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Docket Number: 3AL-004

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PROVISIONAL APPLICATION FOR PATENT COVER SHEET (Small Entity)

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INVENTOR(S)/APPLICANT(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Paul	Kleinberger	Jerusalem, IRRAEL
Ilan	Kleinberger	Jerusalem, ISRAEL
Jack Yehoshua	Mantinband	Efrat, ISRAEL
Hillel	Goldberg	Bet Shemesh, ISRAEL

☐ Additional inventors are being named on page 2 attached hereto

TITLE OF THE INVENTION (280 characters max)

THREE DIMENSIONAL VIEWING SYSTEMS AND METHODS

CORRESPONDENCE ADDRESS

Direct all correspondence to: → Place Customer Number Bar Code Label here

☐ Customer Number

OR

☒ Firm or Individual Name	Gary R. Maze				
Address	The Matthews Firm				
Address	1900 West Loop South, Suite 1800			ZIP	77027
City	Houston	State	Texas	Fax	713-355-9689
Country	United States of America	Telephone	713-355-4200		

ENCLOSED APPLICATION PARTS (check all that apply)

☒ Specification — Number of Pages

☒ Drawing(s) — Number of Sheets

☒ Small Entity Statement

☐ Other (specify)

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT (check one)

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The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☒ No.

☐ Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,

SIGNATURE [signature]

Date 7 Jan 2000

TYPED or PRINTED NAME Gary R. Maze

REGISTRATION NO. (if appropriate) 42,851

TELEPHONE 713-355-4200

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Invention: THREE DIMENSIONAL VIEWING SYSTEMS AND METHODS

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THREE DIMENSIONAL VIEWING SYSTEMS AND METHODS

The current application claims priority from United States Provisional Application 60/152,133 filed on September 7, 1999 and United States Provisional Application 60/168,351 filed on December 1, 1999.

SPECIFICATION

Prior documents

The reader of this document is assumed to be familiar with

- U.S. Patent 5822117 to Kleinberger et al., and referred to in the following as "PAT" herein incorporated by reference.
- PCT application WO 97/26577 dated 24 July 1997, and referred to in the following as "PCT" herein incorporated by reference.
- U.S. Patent 2631496 to Miles P. Rehorn

Note on the figures

Except as otherwise noted, all the figures of this document refer to systems as see from above. Thus elements of the figures represented by rectangles (such as element 101 in figure 1) generally represent vertical strips or similar objects in a plane understood to be perpendicular to the plane of the figure.

Figures 1, 2, and 4 present pairs of images contrasting two states of a same apparatus. To facilitate comparison, the right-hand image is presented as a mirror image (with appropriate changes) of the left-hand image. The discussion will nevertheless continue to refer to the placement of objects as would be appropriate in discussing the left-hand image. For example, eye 30 will be referred to as the left eye and eye 20 as the right eye, despite the fact that in the right-hand image 1b, a near-mirror-image of figure 1a, eye 30 actually appears to the right of eye 20.

Definitions

Terms used in this document and which are defined in the definitions section of PCT are to be understood as they are defined in PCT.

In the following paragraphs some additional terms are defined, and, for the convenience of the reader, additional explanatory material relating to some terms defined in PCT is also

provided.

"left image" and **"right image"** refer to the pair of images which together constitute a stereoscopic display pair, the former presenting a scene as it would appear to the left eye of an observer, the latter to the scene as it would appear to the right eye of an observer. Stereoscopic and autostereoscopic display systems generally seek to present a left image to a viewer's left eye and a right image to a viewer's right eye, and to prevent light from the left image from reaching the right eye and light from the right image from reaching the left eye.

"inappropriate image" refers to that image which, if seen by a particular eye, will interfere with or degrade the autostereoscopic effect. Thus with respect to the left eye, the right image is the inappropriate image, and with respect to the right eye, the left image is the inappropriate image. Similarly, the **"appropriate image"** refers to the left image with respect to the left eye, and the right image with respect to the right eye.

"our two-layer polarizer systems" refers to the systems described in PAT in figures 6 – 12 and in the accompanying text which relates to those figures

"classical parallax-barrier system" refers to the well-known system for autostereoscopy by which an optical barrier consisting of transparent and opaque vertical strips is interposed at a particular distance from a display, and the display presents side-by-side pixels from alternating sources, pixels from a left image alternating with pixels from a right image.

"movement-permissive system" refers to the technique described in figures 32-33 of both PAT and PCT, and in figure 33a of PCT. This technique allows for a certain amount of movement of the viewer's head and eyes, without said movement causing degradation of the autostereoscopic effect nor of the quality of the display as it appears to the viewer. The movement-permissive system can be used in our two-layer polarizer systems, and in the classical parallax-barrier system, and in various other contexts. An additional advantage of the movement-permissive

system is that systems in which it is incorporated are relatively indifferent to minor variations in the exact placement of, and optical qualities of the edges of, the various optical elements of which the systems are composed. For example, a parallax-barrier system including the movement-permissive system would be somewhat insensitive to minor errors of placement of the line of division between the transparent and the opaque segments of the parallax barrier.

"birefringent layer with individually switchable elements" refers to a layer with a plurality of individually controllable elements of "switchable light rotating means", (as that term is defined in PCT). In other words, it refers to any arrangement, such as that described in PAT figure 19, in which a device such as a liquid crystal with individually addressable areas is used in connection with a control system in such a way that at any given time, any particular configuration of all, some, or none of the individually switchable elements will turn the polarization orientation of light passing through them. As a common example, a "birefringent layer with individually switchable elements", when sandwiched between two flat polarizing layers, constitutes a popular form of notebook computer screen. For simplicity, the birefringent layers with individually switchable elements referred to in the following are drawn as if the individually addressable elements are parallel vertical strips, and this is indeed a convenient configuration for most of the embodiments described in the following, but it should be understood that this definition, and the embodiments incorporating birefringent layers with individually switchable elements as described in the following, are not limited to that particular configuration. Standard LCDs with two-dimensional arrays of addressable elements could be used, as well as other configurations.

"our mechanical head-tracking system" refers to the system described in PCT with reference to elements 134 and 134a of figure 18 therein.

"our electronic head-tracking system" refers to the system described in PCT with reference to figures 18-23, which uses a birefringent layer with individually switchable elements.

"our head-tracking systems" refers to either or both of our mechanical head-tracking system

and our electronic head-tracking system.

"sweet spot" refers to that position or positions from which a viewer can see the stereoscopic image displayed by an autostereoscopic display. In the classical parallax-barrier system the sweet spot is intrinsically rather small. When that system is enhanced using our movement-permissive system, the sweet spot is enlarged.

"display pixels" refers to the physical pixel elements of display devices with fixed physical pixels, such as LCD display devices.

"image pixels" refers to picture elements of the left and right images, each of which may be displayed by zero, one, or several physical pixels on a display device which has physical pixels, or may be displayed, or not displayed, in some area of a display device which is not itself intrinsically divided into physical pixels.

"head-tracking sensor" is an apparatus capable of detecting and reporting information about the position of the viewers' eyes with respect to the display and the autostereoscopic apparatus. The head-tracking sensor will preferably be a detector of the position of the eyes of the viewer(s), but it may also be a detector of the position of the head of the viewer, or a detector of the position of an object worn on the head of the viewer, from which an estimate of the position of the eyes may be derived. Such detectors are available from various commercial sources. It may also be any other apparatus capable of supplying information relevant to the viewers' eye positions. For example, a device in the style of a television 'remote control' unit, through which a user might supply information about his head position by pressing buttons an a hand-held control device, would be included in the definition of a "head-tracking sensor" as that term is used in this document.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

Improvements in parallax barrier technology: time-multiplexing of elements of the images

Classical parallax barrier systems have intrinsically low resolution, since 50% of the display surface is unavailable to each eye. They also have an intrinsically small sweet spot, since they depend on the left and right eyes being in particular positions with respect to the parallax barrier and the display, and if the eyes deviate from their expected positions this causes degradation of the perceived stereoscopic image. Our movement-permissive system, described in PAT and PCT, is a method for enlarging the sweet spot, but it requires the sacrifice of even more display area. Thus, a classical parallax barrier system might incorporate our movement-permissive system to allow some freedom of head movement and/or variability in interpupillary distances among viewers, yet it might show each of the left and right images in as little as e.g. 30% of the display space. This would result in a very rough and low-resolution picture.

The problem of the inherently low resolution of parallax barrier systems is partly solved by the method described in PAT in the discussion of figures 14, 14b, and 15, where is presented a system for time-multiplexing image elements while using a parallax barrier. According to that method, through time-multiplexing, each part of the surface of the display can be used to show parts of both the left image and of the right image, each at different times. Thus through persistence of vision, the impression is created that both left and right images are continuous across the display.

That method can be combined with our movement-permissive system either by adding opaque areas to the barrier layer, (as described in PCT fig. 33a) or by leaving certain areas of the display surface dark at all times (as described in PAT and PCT fig. 32). This combination would allow for some freedom of movement of the head of the viewer, and would give less of an impression of low resolution than would the classical parallax barrier system.

However, the combined systems would still have two distinct disadvantages. First, the size of the subdivisions of the barrier layer would need to be quite small, otherwise the opaque areas of the blocking layer (or alternatively the non-displaying areas of the display surface) would be visible to the viewer and disrupt his view of the display. Second, even if the opaque (or non-displaying) areas were small enough so that they eye could not resolve them as discreet obstacles to the view of the display, nevertheless they would cause a lower-resolution display than could be achieved were they not in use.

The alternate method for combining time-multiplexing of elements of the left and right images

with parallax-barrier technology presented in PAT in figures 15, 15, and in particular 14a, however, is fully compatible with the movement-permissive system, and can avoid these disadvantages.

The method for doing so is made explicit in figure 1 of this document. If we first examine the part of figure 1 labeled "figure 1a" in isolation, we see an arrangement similar to that described in fig. 33a of PCT. Layers 50 and 90 are uniform polarizing filters, and layer 60 is a birefringent layer with individually switchable elements. Layers 50, 60, and 90 together constitute layer 40, a parallax barrier layer which permits left eye 30 to see left image pixels in areas 101, 102, and 103 of display 10, and permits right eye 20 to see right image pixels in areas 104, 105, and 106 of display 10, while preventing each eye from seeing any light from the inappropriate image. The individual elements (601-615 etc.) of layer 60 are controlled by control element 80. Control element 80 also controls display 10, in that it chooses whether a left image pixel or a right image pixel will be displayed at a given time in each particular area of display 10. As described in PAT and PCT with respect to figures 14-15 and 18-23 there, the birefringent effect of the individual elements of layer 60 are switched on and off selectively in order to line up the transparent portions with layer 40 with the position of the viewer's eyes, using information provided by sensor 85 which can be a head-tracking system, a manual remote control, or some other source of information about the position of the viewer. As may be seen from inspection of figure 1a, if for example the viewer's eye 30 were to move to the right (towards the bottom of the figure), sensor 85 will provide this information to control element 80 which will cause area 604 to switch its birefringence, causing that portion of layer 40 to become transparent, and will cause area 601 to switch its birefringence causing its portion of layer 40 to become opaque. Thus the arrangement described in figure 1a can be used, as described in PAT and PCT, to adapt the apparatus for autostereoscopic viewing while the viewer moves from left to right with respect to the display. It may further be seen that the selection of opaque and transparent areas on layer 40 may optionally be made in such a way as to implement our movement-permissive system: if the opaque areas on layer 40 are somewhat larger than the transparent areas (as is shown in figure 1), then the effect is that described in figure 33a of PCT. Lines 510, 512, 514, and 516 here recall the lines similarly numbered in figure 32 of PCT; they delimit the area within which the

viewer's eyes may move without causing the eyes to see less light from their appropriate images, nor any light from their inappropriate images.

Comparison of figure 1a to figure 1b reveals yet another advantage of this arrangement. In both figures the viewer's eyes 20 and 30 have identical positions and distances with respect to the display. The difference between figures 1a and 1b is that the control element 80 has used its capacities for switching the transparent areas of display 40 and its capacity for determining the position of the left and right image pixels on display 10 in such a manner as to change the opaque areas of 40 and the display areas of 10 without requiring movement on the part of the viewer. In figure 1a the areas of layer 40 which include 601, 602, 603, and 611, 612, and 613 are transparent, and a left image pixel is displayed on areas 101,102, and 103 of display 10 while a right image pixel is displayed in areas 104, 105, and 106 of display 10. In figure 1b the areas of layer 40 which include 603, 604, 605, and 613, 614, and 615 are transparent, and a left image pixel is displayed on areas 102,103, and 104 of display10 while a right image pixel is displayed in areas 105, 106, and 107.

Taken together, figures 1a and 1b demonstrate that the arrangement depicted is capable of altering the presentation of the autostereoscopic image, at electronic speeds, in such a manner that all areas of display 10 can be used both for left image pixels and for right image pixels, at different times, and further that while the arrangement provides for large opaque areas of layer 40, as required by the movement-permissive system, those areas may be shifted around layer 40 rather than be permanently fixed in any particular position.

These arrangements, together with the well-known phenomenon of persistence of vision, have several beneficial effects.

First, switching the display in such a way that all areas of the display will sometimes display elements from the left image, and sometimes display elements from the right image, will, by persistence of vision, create the impression of a continuous, full-resolution display.

Second, using blocking areas of layer 40 which are wider than the transparent areas of layer 40 creates the movement-permissive system. Use of that system relaxes the requirements for complete accuracy on the part of head-tracking sensor system 85; approximately accurate reporting of the viewer's eye positions will be good enough, since the movement-permissive system makes the arrangement as a whole tolerant of a certain margin of error. There is an

additional advantage to the incorporation of the movement-permissive system in this context: were complete accuracy required, the individually addressable elements on layer 60 would need to be extremely small, since they must be turned on and off as discrete units, yet must approximate the motion of the viewer's eyes, which is continuous. Use of the movement-permissive system in this context allows the individually addressable elements of layer 60 to be larger, since minor errors in placement of the end-points of the switched areas on layer 60 will also be covered by the margin of error allowed by the movement-permissive system. Thus use of that system allows layer 60 to be less fine-grained, consequently less expensive.

Third, the fact that the opaque areas used to create the movement-permissive effect are not fixed but variable makes it possible to use larger opaque areas than would otherwise be the case, without thereby (because of persistence of vision) producing the impression of a low-resolution image.

Another embodiment of this invention is presented in Figure 2. Elements of figure 2 with the same numbers as elements in figure 1 have the same functions as those described in the discussion of figure 1. The difference between the embodiment described by figure 1 and that described by figure 2 is simply that the choices imposed by control element 80 are different, with the result that whereas figure 1 implemented the movement-permissive system according to the method described in PCT figure 33a, (extra opaque areas on parallax blocking layer 40), figure 2 implements the movement-permissive system according to the method described in PAT and PCT figure 32, with non-displaying areas on display 10. In part 2a of figure 2, for example, control element 80 has chosen to create on layer 40 opaque areas which are approximately equal in width to the transparent areas it creates on layer 40 (as indicated by the shading, the shaded areas being the opaque areas), but control element 80 has also chosen to display a left image pixel in area 102 of display 10, and a right image in area 105 in display 10, but to leave areas 101, 103, 104, 106, 107 etc. dark, that is, those areas display neither the left image pixels nor right image pixels. The effect is as described in PCT, that the viewer's eye 30 can move anywhere within the area between lines 510 and 512, and eye 20 can move anywhere in the area between lines 514 and 516, without that movement affecting the quality of the viewer's experience of the autostereoscopic view.

Part 2b of figure 2 depicts the same apparatus as is depicted by part 2a, but at a different time.

Comparison of parts 2a and 2b serves to show that for a given position of the apparatus and of the viewer there exists a plurality of different combinations of transparent and opaque elements on layer 60, and of areas of display 10 displaying left image pixels, right image pixels, or not displaying anything, such that the principle described in the preceding paragraph is nevertheless observed. In practice, the apparatus, under the control of control element 80, can switch rapidly among two or more such alternative arrangements. As noted with respect to figure 1, such rapid alternation of arrangements will provide the advantages of permitting simultaneous use of our electronic headtracking system and our movement permissive system, and of allowing relatively large areas of the display to be used as non-display areas, and yet will create, due to persistence of vision, the impression of a continuous high-resolution display.

<u>Adapting an autostereoscopic system with a "sweet spot" to the position of a viewer by modifying the display.</u>

Figure 3 shows yet another way of enabling an autostereoscopic display system with a "sweet spot", such as a classical parallax barrier system, to adjust itself to the changing position of the viewer with respect to the display.

The classical parallax barrier system, and various adaptations of it, and various similar systems, require that the viewer view the apparatus from a "sweet spot"; only from particular positions can the autostereoscopic effect be seen. PCT, in figures 13-15 and 19, described methods of moving and of modifying the parallax barrier in ways which adapt the device to movement of the viewer with respect to the device, and we have discussed additional uses and advantages of such an arrangement in the description of figures 1 and 2, above.

Figure 3 presents another method by which the configuration of a parallax-barrier system may be modified so as to adapt itself to changes in the position of the viewer. In this system the effect is achieved by modifying not the parallax barrier, but the displayed image.

The viewer's left eye (330 or 430) and right eye (320 or 420) see light from the images displayed on display 10 after that light passes through the barrier layer 40. For simplicity the figure represents the classical parallax barrier system, with fixed transparent segments alternating with fixed opaque segments, but it is clear that the system described in the following will apply also to various adaptations of the parallax barrier system, including those described in PAT and

PCT, those described in figures 1-2 above, those described in figure 11 below, and others.

Head-tracking sensor 85 supplies information to the system about the position from which the viewer (or viewers) is/are viewing the display.

Positions 330 and 320 represent one possible position of the viewer with respect to the display, with left eye at 330 and right eye 320. Positions 430 and 420 represent a second possible position of viewer with respect to the display, with left eye at 430 and right eye at 420. These two positions (430/420 and 330/320) represent two arbitrary positions of the viewer, at approximately equal distances from display 10. (Note that for the sake of clarity of figure 3, the size of the individual subdivisions of layer 40 and of the marked areas of display 10 have been exaggerated. In the preferred embodiment these would be relatively much smaller than the scale on which they are drawn in the figure, and hence would be capable of much finer adjustments of position than their scale in the figure would otherwise imply.)

Considering first the situation when the viewer's left and right eyes are in positions 330 and 320 respectively, areas 354-356 and 360-362 of display 10 will display left image pixels and areas 351-353 and 357-359 of display 10 will display right image pixels, according to the classical parallax-barrier method. This will allow the viewer, when in that position, to view the autostereoscopic image, with each eye seeing its appropriate image and not seeing any part of the inappropriate image.

When head-tracking sensor 85 detects that the viewer's left eye has moved, say, from position 330 to position 430, and his right eye has moved from position 320 to position 420, that information is transmitted to control element 80, which causes display 10 to change the manner in which the left and right images are displayed. The viewer having moved to his right, the display image moves to the viewer's left. Areas 353-355 and 359-361 of display 10 will now display left image pixels, and areas 350-352 and 356-358 will display right image pixels. As a result the autostereoscopic effect is preserved, in that each eye continues to see light from its appropriate image, and not to see light from its inappropriate image. (Of course, the fact that figure 3 assigns three numbered areas for each "image pixel" is arbitrary, and is not intended to imply that the set is limited to that particular number of display pixels, nor that the display is necessarily subdivided into physically distinct display pixels).

There are a variety of manners in which this transformation of the position of the image pixels might be accomplished.

In one implementation control element 80 controls a mechanical motor-driven device which simply moves the display a specified amount, or which moves the display until a feed-back device 83 indicates that the display is in the desired position.

In another implementation display 10 is a display with discrete addressable display pixel elements (such as a standard LCD display) under control of control element 80. In this case control element 80, using information provided by head-tracking sensor 85, calculates which images should be made visible in which physical positions, and simply directs left and right image pixels to the appropriate physical display pixels of display 10.

In yet another implementation, display 10 is a display such as a laser light display, in which individual picture elements may be directed to any part of the display surface, and they are simply directed as determined by control element 80.

Yet another implementation is appropriate for display technologies in which some general characteristics of the display, such as the horizontal positioning of the display as a whole, and the width of the display as a whole, are subject to central electronic or mechanical control. This is the case, for example, in standard CRT technology such as is used in most personal computer displays and many CRT-based televisions. In many such systems analog or digital controls are provided which allow the user to adjust the horizontal positioning of the image on the screen, the width of the display as a whole, etc. In an embodiment appropriate to displays of this type, control element 80 exercises just such control, controlling the horizontal positioning of the image in such a manner that the image elements appear in the appropriate physical areas of the display, as shown in figure 3.

CRT displays may be somewhat unstable in that the size and position of the display may vary with changes in line voltages, temperature of the apparatus, and so on. (This is one of the reasons for which analog controls of image size and position are typically provided.) Consequently this embodiment may also include a feedback mechanism 83 which detects the display's actual position on the display device and modifies the input parameters of the display device appropriately so that the displayed image will appear, and remain, in the position determined for it by control element 80.

It is clear that the technique described above and in figure 3 is compatible with our movement-permissive systems and our head-tracking systems as described in PCT and PAT, as well as the various systems described in the current document, and various other autostereoscopic techniques, and that it can be used in a manner independent of these other systems, or in conjunction with them.

Adapting parallax barrier autostereoscopic displays to variable distances of the viewer from the display.

Figure 4 describes a system for adapting autostereoscopic displays to movement of a viewer towards and away from the display.

In PAT and PCT and in the discussions of figures 1-3 above, we discussed various methods for configuring an autostereoscopic display apparatus so that the autostereoscopic effect will be preserved while a viewer moves with respect to the apparatus. While the movement-permissive system can tolerate some movement towards and away from the display, the various discussions of the headtracking systems, including those of PAT, PCT, and of figures 1-3 above, related primarily to movement of a viewer sideways (left to right, or right to left) with respect to the apparatus. Although some of the mechanisms described are inherently capable of adapting to movement of the viewer in the direction perpendicular to the plane of the display (i.e. towards the display and away from the display), this fact was not everywhere made explicit.

One exception to this is in PAT and PCT figures 18-23, where a system is presented for adapting an autostereoscopic display to movement of the viewer in the direction perpendicular to the plane of the display (towards it or away from it). However, the system there described has the disadvantage of requiring a plurality of liquid crystals at various distances from the display, a relatively expensive solution.

Figure 4, then, makes explicit capabilities implicit in the PAT and PCT systems, in that it shows a relatively more simple method by which an autostereoscopic system may adapt to movement of a viewer towards or away from the display, using only one liquid crystal layer in the case of a parallax barrier system, or only two liquid crystal layers in the case of our two-layer polarizer system.

Numbered elements carried over into Figure 4 from Figures 1-3 have the same definition and function as they did in those drawings.

In one embodiment shown in figure 4, layer 40 is a parallax barrier based on a birefringent layer with individually switchable elements, as was described above in the discussion of figure 1 and elsewhere. Element 10 is a display on which areas have been marked; the meaning of these areas is the same as that of the areas marked on display 10 in figure 3.

Images may be moved left and right on the display surface, as was discussed above in connection with figure 3. It is also clear that the same various methods that can be used to shift the images left and right can also be used to expand and contract both the image as a whole, and the image pixels of which it is composed. In the current embodiment, the image pixels (610, 620) of display 10 are capable of being so expanded and contracted.

Examination of the mathematical relationships expressed in PAT fig 24 and in the discussion thereof will show that if positions of the viewers eyes and the positions of layer 40 and of display 10 are given, then if the starting position of a single image pixel on display 10 is given, the size and position both of all the opaque and transparent areas of layer 40, and the size and position of all the image pixels on display 10 are uniquely determined. Consequently, if layer 40 is capable of being subdivided into opaque and transparent sections of approximately the desired size, and the left and right image pixels on display 10 can be placed appropriately, then it is possible for the display apparatus to adapt itself to the viewer's position with respect to the display, and to maintain that adaptation while varying the configuration of the apparatus while the viewer moves both left and right and towards and away from the display.

The contrast between figure 4a and 4b graphically demonstrates this phenomenon. The distance between the eyes is the same, their sideways position with respect to display 10 is the same, and the distance 202 separating barrier layer 40 from display 10 is identical. Figures 4a and 4b differ only in that the distance 230 of eyes 330 and 320 from barrier 40 and from display 10 is considerably greater in 4a than is the distance 240 of eyes 430 and 420 from barrier 40 in figure 4b.

Thus figures 4a and 4b can represent the same apparatus at different times, the viewer having viewed the display from distance 230 at a first time T1, and then moved closer to the display to view it at distance 240 at a later time T2. The changes in the configuration of the apparatus from T1 to T2 constitute the adaptation of the apparatus to changes in the distance of the viewer to the display.

As may be seen from inspection of figure 4, and taking into account our previous discussions of the functioning of layer 40 and the constellation of display 10, head-tracking sensor 85, control element 80, and feedback mechanism 83, the device can easily adapt to this change in the viewer's position by creating appropriate transparent areas on layer 40, e.g. at areas 510, appropriate opaque areas on layer 40, e.g. at areas 520, and causing display 10 to display left image pixels at areas 610 and right image pixels at areas 620.

It is noteworthy that the apparatus as described can also adapt itself to changes in the position of the viewer's eyes when the viewer tilts his head sideways. The net effect of his doing so, so far as the autostereoscopic device is concerned, is simply to reduce the angular distance between the eyes, just as would have been the case if the viewer had distanced himself from the display. Thus the same adaptation which allows him to see the autostereoscopic effect as he moves away from the display will also allow him to see the autostereoscopic effect when he tilts his head sideways.

Adapting our two-layer polarizing autostereoscopic system to variable distances of the viewer from the display.

Figure 5 shows a similar implementation of this invention, this time based not on a parallax barrier but on our two-layer polarizing system as described in PAT. In this case 50 is a polarizing layer, 55 is a birefringent layer with individually switchable elements, 65 is yet another birefringent layer with individually switchable elements, 90 is a polarizing layer, and 10 is a display. The reader familiar with the discussion of our two-layer polarizer autostereoscopic systems in PAT and PCT will recognize that the apparatus here described fulfills the definition of such a system. Here we merely point out that the above discussion of the adaptability of the apparatus to changing distances of the viewer is equally applicable to the two-layer polarizer system.

Yet another embodiment is described by figure 5 if display 10 is a display emitting polarized light, such as an LCD display. In this case the layer 50 is unnecessary as its function is provided within display 10. Other considerations regarding the adaptation of the apparatus to movement of the viewer are identical to those discussed above.

In both of the embodiments represented by figure 5, control element 80 controls both the switching of the switchable elements of birefringent layers 55 and 65, and also coordinates the

appearance of the left image and the right image in the appropriate areas of display 10.

To summarize the embodiments described by figures 4 and 5, we have seen that as the viewer changes his distance from the display, the apparatus can adapt to his changing position by altering the size of areas marked as 510, 520, 610, and 620 on the figures. If the position of the layers remains constant and the viewer approaches more closely, the overall geometry of the apparatus can be maintained if the size of areas 510 and 520 of layer 40 (or layer 55) grow smaller in proportion to areas 610 and 620 of display 10 (or of layer 65), and conversely as the viewer moves further away, elements 510 and 520 must grow somewhat larger in proportion to the size of the elements 610 and 620.

Additional blocking layer, for two-layer polarizer system

The head-tracking system described in PAT can easily be used together with the movement-permissive system described in PAT/PCT when the system as a whole is constituted by one fixed polarizing layer and one variable polarizing layer. Opaque elements, as required by the movement-permissive system, would be easy to integrate into the manufacture of a fixed polarizing layer.

When the system is modified, as we have done for example in the embodiment described in figure 5 above, and is based on two birefringent layers with individually switchable elements, then it is no longer useful to manufacture fixed opaque elements as part of one of the polarizing layers. The areas on layers 55 and 65 which need to be opaque according to the principles of the movement-permissive system are the areas around the points of transition from elements with one polarization orientation to elements of the other polarization orientation. However, as we explained above in reference the embodiment described by figure 5, those points of transition are not fixed, but moveable. Consequently to integrate the movement-permissive system into an embodiment such as described by figure 5, or into any embodiment containing a birefringent layer with individually switchable elements in which the opaque areas are to be integrated into such a layer, we must provide a moveable set of opaque areas whose placement is also controlled by the control element 80. Control element 80 can then cause opaque areas to appear and to move in conjunction and coordination with the switching of the individual elements of the birefringent layer controlling the polarization elements, in such a manner as to obtain and to maintain over time the effect described in PCT fig 32-33a.

Figure 6 summarizes this embodiment.

10 is a display.

Optional layer 100 is a fixed uniform polarizing layer.

Layer 110 may be either a fixed polarizing layer such as was described in PAT for layer 56 of figure 6, or else a birefringent layer with individually switchable elements. In the former case, layer 100 is unnecessary, since layer 110 polarizes light passing through it. In the latter case layer 100 is included; it polarizes light from display 10, some of which may or not be turned by the switchable birefringent areas of layer 110.

Note also that if 10 were a display generating polarized light, such as for example an LCD display such as is popular in notebook computers, then in this case also, layer 100 would be unnecessary as the light from display 10 would already be polarized.

120 is an optional birefringent layer without individually switchable elements: this layer can be used but is unnecessary if 110 is a birefringent layer with individually switchable elements, since the effect of reversing the birefringent status of layer 120 would be similar or identical to the effect of reversing the birefringent status of each of the switchable elements of layer 110.

130 is a birefringent layer with individually switchable elements, and 140 is a uniform polarizing layer.

The cumulative effect of using layers 10, 100, 110, 120, 130, and 140, assuming that the individual birefringent elements of layers 110 and 130 are switched in the manner described in PAT, PCT, and above, is an autostereoscopic system without the movement-permissive system, but which incorporates our electronic head-tracking system.

The addition of layers 150 and 160 adds the movement-permissive system to the apparatus. 150 is a birefringent layer with individually switchable elements. 160 is a uniform polarizing layer. The combination of the uniform polarizing layers 140 and 160 with birefringent layer with individually switchable elements 150 constitutes a system well known in the art, and used to e.g. create opaque areas in the displays of most notebook computers and digital watches. Thus, layers 140, 150, and 160 taken together can produce opaque areas wherever is desired along the width of the apparatus. Layers 150, 130, 120 (if used), and 110 (if it incorporates individually switchable elements) can all be connected to a common control element 80 which controls the

placement of image pixels on display 10 and the switching of birefringent elements of layers 150, 130, and (optionally) 110, and which in turn may respond to information provided by a head-tracking sensor 85.

It will be evident to the reader normally skilled in the art that the arrangement described by figure 6 could optionally be constructed in such a way that light would transverse it from the opposite direction, that is, in such a way that the combination of layers 160, 150, 140, and 130 is placed close to display 10, followed by (optional) layer 120, then layer 110, and then with layer 100 closest to the eyes of the viewer.

In other words, the addition of layers 150 and 160 to systems such as that described above in reference to figure 5, allows for opaque elements (required by the movement-permissive system) to be placed electronically at the points where those blocking elements would be appropriate as described in PCT fig.32 and fig 33a, yet allows it to continuously conform to the variable geometry, potentially undergoing rapid switching under electronic control, of the birefringent layers with individually switchable elements incorporated in the system. Thus is produced a system with the benefits of electronic head tracking and also the movement-permissive systems, capable of adapting both to sideways movement of the viewer and to forward and back movement of the viewer, and even to a large extent to tilting of the head of the viewer, all at electronic speeds and with no moving parts.

Autostereoscopic system using our two-layer polarizing system without temporal multiplexing.

One of the problems of many of the stereoscopic and autostereoscopic systems known to the art is the problem of flickering, when the pair of stereoscopic images are time-multiplexed in whole or in part, that is, when the apparatus causes the viewer's eyes to alternate in their viewing of the display or of parts of the display. Many stereoscopic and autostereoscopic displays tend to flicker, which flickering is distressing to viewers and hence constitutes a serious disadvantage of those systems.

On the other hand, of those stereoscopic systems and autostereoscopic systems known to the art which do not involve time-multiplexing and consequently do not flicker, many suffer the disadvantage that they use some portions of the screen to display the left image and other portions of the screen to display the right image, consequently both images appear at relatively

low resolution, because the view presented to each eye includes large areas of the display surface which are not displaying that eye's appropriate image.

Figure 7 presents a manner in which the techniques described in PCT and PAT and in the figures described herein can be used to create an autostereoscopic system which does not use time multiplexing, hence does not flicker, yet also presents both eye's images at full or nearly-full resolution.

Rehorn in his patent U.S. 2631496 in his figure 1 describes an "image B" which is an image display with particular characteristics. For a full definition the reader is referred to Rehorn's text and drawings, but the form of "image B" may be summarized as follows: a display presents two sets of areas distributed across the display with areas from one set alternating with areas from the second set, the areas are in the form of strips of approximately equal width, the first set of which presents the left image with a first polarization orientation A and also the right image with a second polarization orientation B orthogonal to A, and a second set which presents the right image with orientation A and the left image with orientation B.

In our figure 7 display layer 500 is a display surface displaying left and right images as described by Rehorn in his description of his "image B", and in the preceding paragraph. The shaded portions 510 of layer 500 represent areas of the first set, as defined above, and the unshaded portions 520 represent areas of the second set. Layer 130 is a birefringent layer with individually switchable elements, and layer 140 is a uniform polarizing layer. Layers 150 and 160 are optional; their meaning is the same in this figure as was defined for figure 6.

Assume that the orientation of layer 140 is such that it is transparent to light of orientation B and opaque to light of orientation A. Further assume that in the unshaded areas 620 of layer 130 the birefringent effect of layer 130 is inactive, while shaded areas 610 of layer 130 turn light by 90 degrees.

The reader can see by inspection of figure 7 that right eye 20 sees each shaded area 510 of layer 500 through a shaded area 610 of layer 130, and sees each unshaded area 520 of layer 500 through an unshaded area 620 of layer 130. According to our definitions, light from the right image from areas 510 comes from the first set of areas, consequently is in orientation B. When it passes through shaded areas 620 of layer 130 it is turned 90 degrees into orientation A. Layer 140 is by assumption transparent to light of orientation A, so in areas 510 the right image is

visible to the right eye.

Similarly, the right image displayed in areas 520 is in orientation A, and passes through unshaded portions 610 of layer 130, which are inactive in birefringence and do not affect the orientation of light passing through them. Consequently light from the right image from areas 520 also reaches layer 140 in orientation A and pass through to eye 20. Thus right eye 20 can see the right image on all areas of display 500. At the same time, light from the left image was oriented orthogonal to light from the right image in each of those areas. Consequently, such light, passing through the same areas of layer 130, will arrive at layer 140 with Orientation B, and be blocked. Thus the right eye sees the right image everywhere on display 500, and does not see any light from the left image.

The reader can again see by inspection of figure 7 that left eye 30 sees each shaded area 510 of layer 500 through an unshaded area 620 of layer 130, and sees each unshaded area 520 of layer 500 through a shaded area 610 of layer 130. Light from areas 510 from the left image is in Orientation A. On its way to left eye 30 it is unchanged by the unshaded areas 620 of layer 30, and so can pass through layer 140 to left eye 30. However light from the right image, being in Orientation B and unchanged by layer 130 will arrive at 140 in Orientation B and be blocked from left eye 30. Meanwhile from areas 520 light from the left image is in Orientation B, and passes through areas 610 of layer 130, which turn it 90 degrees into the Orientation A, consequently light from the left image from areas 520 also passes through filter 140 to the left eye. Light from the right image from areas 520 is in Orientation A, is turned by areas 610 and arrives at 140 in Orientation B and is blocked.

Consequently the left eye sees the left image but not the right image through the whole width of display 500, and the right eye sees the right image and not the left image through the whole width of the display. Element 130 is a birefringent layer with individually switchable elements and elements 80 and 85 are the same as was defined in previous figures, consequently the apparatus includes our head-tracking system. Optional layers 150 and 160 provide our movement-permissive system. If display 500 is capable of altering the placement and size of areas 510 and 520, then the apparatus can use the technology described above in the context of figure 4, and the apparatus is consequently capable of adapting to viewers' movements as they move closer to and further from the display as well, and to adapt also to their movement when

they tilt their heads.

<u>**Autostereoscopic apparatus using a partially transparent mirror.**</u>

In our discussion of figure 7 we assumed that display layer 500 in that figure is a display surface displaying left and right images as described by Rehorn in his description of his "image B". Figure 8 describes one way of producing the such a display.

In Figure 8, 10 and 15 are display sources such as CRT displays. 90 and 95 are uniform polarizing filters, orthogonal to each other. That is, if light originating in display 10 and passing through filter 90 is polarized in Orientation A, then light originating in display 15 and passing through filter 95 will be polarized in Orientation B, 90 degrees from A.

115 is a partially transparent and partially reflective surface, such as a partially silvered mirror. It allows some of the light (typically approximately half the light) from display 10 to pass through it to layer 190, and it reflects some of the light (typically approximately half the light) from display 15 onto layer 190. Surface 115 either preserves the polarization orientation of light passing through it and reflected from it, or else transforms the orientations of reflected and of transmitted light by an equal degree, or else there is a predictable relationship between the degree to which it turns transmitted light and the degree to which it turns reflected light, in which case the orientations of filters 90 and 95 can be adjusted so that light from display 10, after passing through surface 115, is in an orientation orthogonal to that of light from display 15 after being reflected from surface 115.

One of the two displays 10 and 15 displays a left image, the other a right image. (The image on display 15 will need to be reversed left-to-right, since the viewer sees a "mirror image" of that image, with the areas originally on the left side of the screen as would normally be seen by the viewer transposed to the apparent right side of the screen by the reflective process. Transposing the reflected image at the display source allows it to correspond appropriately with the non-reflected image from display 10.)

<u>**In one embodiment layer 190 is a fixed layer alternating active in light rotation with areas inactive in light rotation.**</u>

In another embodiment layer 190 is a birefringent layer with individually switchable elements, under control of control element 80 which receives information from head-tracking sensor 85. <u>The birefringence of areas of layer 190 is switched is the same manner, and with the same</u>

function, as that described in the context of layer 65 of figure 5.

In both cases, layer 190 presents areas active in light rotation, marked as shaded areas 192, and areas inactive in light rotation, marked as unshaded areas 194.

Assume that the left image arrives at 190 in an orientation B. Then shaded areas 192 will turn it to an orientation A orthogonal to B, and unshaded areas 194 will leave it in orientation B. (Or, by the definition of "active/inactive in light rotation", areas 194 will turn it to B + n, and areas 192 will turn it to A + n, which is to say B + n + 90 degrees. For simplicity, our disucssion will assume that the areas inactive in light rotation have no birefringent effect, but our description should be taken to include all the cases described by the definition of "active/inactive in light rotation", with the obvious necessary changes implied.)

The right image arrives at layer 190 in orientation A, orthogonal to orientation B. Passing through the same shaded areas 192, the right image is turned to orientation B. Passing through unshaded areas 194, the right image is unchanged and remains in orientation A. (Note that the invention is essentially unchanged if light passing through the unshaded areas is rotated by some amount m degrees, and light passing through the shaded areas is rotated by m + 90 degrees.)

The result of this arrangement is that the image passing through layer 190 presents the characteristics described for Rehorn "image B", and described above in the context of figure 7. Layers 130, and 140, and optional layers 150 and ~~160,~~ and elements 80 and 85 refer to the same elements as were depicted in figure 7 and provide the same functionality and advantages. The apparatus as a whole provides the advantages of our electronic head-tracking and movement-permissive systems, provides full resolution for both images, does not flicker, and in the case of the embodiment where layer 190 is a birefringent layer with individually switchable elements, can adapt to changes in the viewer's distance from the apparatus as well.

We note also that if the light from displays10 and 15 is already polarized (as would be the case, for example, with light from an LCD display), then filters 90 and 95 would be unnecessary. Should it be desired to construct the apparatus based e.g. on two LCD displays of identical orientations, then a birefringent layer turning light by 90 degrees could take the place of either filter 90 or filter 95, and the second filter would be unnecessary.

We note also that an alternative construction (not pictured in the figure) is possible, and would produce essentially the same effect. Layer 190 could be placed parallel to surface 115 and

contiguous to it, and polarizers 90 and 95 could have identical orientations rather than orthogonal orientations. Then light moving from display 10 towards the viewer would pass once through layer 190, and light from display 95 would pass twice through layer 190 (once while moving towards surface 115, once, after reflection, while moving from surface 115 towards the viewer). The net effect would be the same as that described above: an "image B" would be produced.

Autostereoscopic apparatus using a two projectors in back projection.

Figure 9 presents another method for achieving the required configuration for the display on layer 500 of figure 7, an "image B"; 310 and 320 are projectors, one projecting a left image and the other a right image. 330 and 340 are uniform polarizing filters, oriented 90 degrees from each other. Consequently light from the left and from the right images arrive at layer 190 with polarization orientations orthogonal to each other.

Layer 195 is a translucent screen on which an image can be projected, and which is capable of transmitting light while preserving its polarization orientation, or which transmits light in a manner which modifies that orientation in a systematic way, such that the differences between the orientation of the first image and that of the second image is preserved.

Layer 190 is the same as the layer 190 described for figure 8.

The effect of layer 190 on light reaching it from the displays is identical to that described in the context of figure 8, and will not be repeated here. The resultant configuration corresponds to that defined by Rehorn as "image B" and described above. Layers 130, 140, 150 and 160 and elements 80 and 85 are as defined for figure 8. Consequently this arrangement as well constitutes an autostereoscopic system with full resolution and no flickering.

Some alternative methods of construction can also be used. Layer 190 may be moved closer to the projectors than to the viewers, with an additional lens used to refocus the image on layer 195; this would allow layer 195 to be smaller and less expensive. Alternatively, layer 195 might be placed between layer 190 and the projectors, rather than between layer 190 and the viewer.

Autostereoscopic apparatus using a single projector in back projection.

Figure 9 also presents yet another embodiment. As before, 320 is a projector, and 340 is a uniform polarizing filter. Layers 195, 190, 130, 140, 150, and 160 and elements 80 and 85 are as described with respect to figure 8. In this embodiment, however, projector 310 and filter 330 are not used. Instead, uniform switchable birefringent element 350 is used, controlled by control

element 80. The purpose of this embodiment is to produce most of the functionality of the previous embodiment, while reducing its cost by requiring only one projector rather than two.

This is a time-multiplexing system. In time T1, element 350 is inactive in turning light, and one of either the left or the right image is projected from projector 320. Light from this image behaves just as was described in the previous embodiment.

In time T2, element 350 is activated by control element 80 and timed to coincide with the projection of the other image (left, if right was previously projected, or right, if left was previously projected). Since element 350 turns the polarized light by 90 degrees, the net effect is that the light of the other image arrives at layer 190 polarized just as light from projector 310 was in figure 8, and undergoes the same processes as were previously described for that light in the context of that figure. In other words, in time T1 a first image is presented, it is entirely visible to its appropriate eye and not visible to the inappropriate eye. In time T2, the other image is presented and it too is entirely visible to its appropriate eye and not visible to its inappropriate eye. While this arrangement does have the disadvantage that it is based on time-sharing of the apparatus and hence has some potential for flickering, it does have the advantage of full resolution for both images, and of lower cost since only a single projector is required. The switching birefringent element 350, since it can be placed near the projector, can be quite small and consequently inexpensive. Note also that 350 might itself be a birefringent layer with individually switchable elements, and be used in such a manner that some areas are initially projected in one orientation and other areas are initially projected in the other orientation, and then in a second phase those orientations are switched. This would have the advantage of making some areas of each image visible to each eye in each phase, and consequently reduce the impression of flickering.

A head tracking sensor using reflected light

Various embodiments of autostereoscopic systems described above, and various other autostereoscopic systems available in commerce or currently under development throughout the world, rely on some form of head-tracking sensor. Yet to the best of our knowledge, no inexpensive head-tracking sensors which reliably report the exact position of the users' eyes is currently available. Figure 10 describes such a system. Control element 80 controls aspects of a display apparatus 81. By way of example display apparatus 81 is here represented as consisting

of one of the embodiments presented above, specifically the embodiment described by figures 1 and 2, but this is intended merely as an example; for present purposes, 81 is any display apparatus which uses information about the position of the viewers' eyes to control some aspect of the functionality of a display apparatus or other apparatus.

88 is a light source. It is positioned somewhere in the area of the display, and shines light in the direction of the viewer or viewers. Light from 88 is reflected from left eye 30 and right eye 20 of the viewer, and detector 85 captures the reflection. (For simplicity of the drawing, 88 and 85 are displaced to the bottom of the drawing, i.e. to the right of the display. In practice it would probably be most convenient to place these objects in some central position, such as just above and near the center of the display.)

Detector 85 is a light detector capable of recognizing light reflected from the viewer's eyes, and reporting the position, or the direction, of the origin of that reflection (i.e. the relative position of the eyes) to control element 80.

One way to accomplish this is for source 88 to provide light to be reflected from the eyes, and for detector 85 to be sensitive that light. In the preferred embodiment, light from light source 88 will be of an intensity and frequency which make it either invisible to the viewer or unobtrusive to him, and it will also be characterized by some pattern or quality which makes it easy to recognize and easy to distinguish from all other light which may be captured by detector 85. For example, light from source 88 might be characterized by some particular frequency not likely to be found in the area of the viewer's eyes, or it might be characterized by a particular pattern of frequencies varying over time, or by a particular pattern of intensities varying over time, or by a particular form or shape of the light-emitting source 88 which would be recognizable in the source's reflected image, or by any combination of the above, or by any other means which will make the image of source 88 reflected from eyes 30 and 20 easily recognizable.

In such an embodiment detector 85 could be, for example, a video camera connected to digitizing hardware and to computing means capable of scanning the digitized image presented by the camera and recognizing that particular part of the picture which represent light with the recognizable characteristics of light from source 88. More simply, 85 might be such a digitizing video camera, sensitive to a particularly light frequency, combined with a light filter which passes only light of approximately that frequency. This combination would make the process

of scanning the image to recognize the reflected light relatively easy, since such light, and only such light, would reach the camera. The essential characteristic of detector 85 is that it can recognize the light from image of source 88 reflected from the eyes of the viewer, and report to control element 80 the angular direction or apparent position of each of the eyes of each of the viewers of the apparatus.

To the extent that light reflected from the eye can be distinguished from other ambient light, the fact that that light originates from source 85 is unimportant. Thus, an adequate implementation of this invention would be constituted by a detector 85 capable of recognizing light reflected from the viewer's eyes, which light originated from the display itself, rather than from source 88.

The reader can easily verify the principle upon which this embodiment is based, by looking into a mirror above which stands a naked light bulb. The image of the bulb reflected from his eyes will be more intense than other light reflected from his face, will more clearly reflect any variations in color or intensity of the light source, and will in fact be seen to consist, on close inspection, of an actual image of the originating light bulb. Thus the problem of "finding the eyes" within the image received by detector 85 is rendered considerably simpler than would be the case by any other means of interpretation of the image of the viewer's face, or by any method of approximating the position of the eyes by detecting or approximating the position of the head.

Several additional advantages of this system may be noted. One is that because the surface of the eye is curved, the angle subtended by the image of source 88 will tend to be quite small even if source 88 is somewhat large. Consequently not only are they eyes easy to locate, but the relative position of the center of sight within the area of the eye is also pinpointed. Of course, if source 88 is displaced somewhat to the side of the display the point of reflection will be displaced somewhat sideways from the center of sight, but this displacement will be a function of the position of source 88 and of detector 85, and an appropriate correction to find the exact center of sight can either be calculated, or can be supplied by manually adjusting the aiming of the device during a once-per-session setup procedure.

An additional advantage of this embodiment is that it provides accurate real-time information about the position of both eyes independently, as distinguished from devices which track the position of the head, or which track the position of some object attached to the head. Since the

position of each eye is tracked independently, the device as a whole is immediately responsive to differences in interpupillary distance from one viewer to another, and it is also capable f responding to tilting of the head (which causes a shortening of the horizontal component of the interpupillary distance, which is the component relevant to most of the uses of head-tracking sensors mentioned herein, and in PAT and PCT. Of course, the apparatus can also provide accurate information about the vertical position of each eye as well, to any apparatus for which that information is of use.

A minor modification of the detection procedure may be called for when the viewer is wearing glasses. Depending on their type and their angle, the viewer's glasses may also reflect a strong and recognizable image of light source 88. The computing means used to analyze the image collected by detector 85 and report the eyes relative positions will in some cases need to take into account the fact that there may be several reflected images of source 88, including one set from the eyes, one set potentially reflected from the front surface of the eyeglasses, and yet another reflected from the back surface of the eyeglasses. This is a relatively small computing problem, however, since the images are distinguishable from each other by their intensity, by differing rates of change in position as the viewer moves from side to side (due to curvature of the glasses), and differences in the size of the image of source 88 (due to greater curvature of the eyes). These and other differences in the images reflected from eyeglasses and those reflected from the eyes themselves will make it possible to distinguish which are the image positions to be reported to control element 80. In the case of particular eyeglasses whose nature and whose angle make it particularly hard to distinguish, the system can simply try reporting one set of reflections, or the other, and query the user as to which one (the upper or the lower, the bigger or the smaller, etc.) worked successfully. Better still, during a setup procedure the viewer wearing glasses can simply turn his head, facing slightly left, then slightly right, while watching the screen. When he does this, the reflections from his eyeglasses will move considerably, while the reflections from his eyes will move very little. This should provide sufficient information to allow even a very simplistic and primitive pattern recognition system to distinguish between the two. Yet another possible solution to the problem of distinguishing between reflections from the eyes and reflections from eyeglasses is to use more than one light source 88, one to each side of the display for example. Reflections of those sources from the eyes will typically be relatively

close together, because of the curvature of the eye. Reflections of those sources from the glasses will typically be relatively far apart or (depending on the glasses' positions and the positions of the multiple sources 88) not appear simultaneously at all. In any case, if light source 88 is far to the side of the display rather than close to it, it will tend to reflect from the eyes, which are relatively curved, and not from the eyeglasses, which are typically relatively flat when compared to the surface of the eye.

Figure 10 can also be used to describe another embodiment of this invention. In this case, the reflected light detected by detector 85 is light reflected from the retina of the viewer's eye, rather than that reflected from the surface of the eye. Here we are utilizing the phenomenon often observed in home photographs taken with flash bulbs, in which a characteristic reflection from the retina (often called "red eye") can be observed in the photograph at the position of the eyes of the people in the photograph. Hence in this embodiment detector 85 recognizes light according to the characteristics of light reflected from the retina, and provides that information to control element 80. Since the exact point of vision of the viewer is by this fully identified, there is no need to distinguish between reflected light which originated from source 88 and reflected light which originated from any other source, including that of the display itself.

<u>Color parallax autostereoscopic system</u>

Our PCT described (in figures 40 and 41 and with respect to various other figures) the use of a color filtration barrier in an autostereoscopic system. A system similar to that described therein, but with certain additional advantages, is described in the following.

The PCT figure 40 shows a situation in which a plurality of RGB triplets 1020 display at least a part of a left image, and these alternate a plurality of RGB triplets 1030 displaying at least a part of a right image. This arrangement is convenient to many types of displays, which display colors by showing combinations of primary colors combined in selected intensities. Moreover, many types of displays incorporate display pixels which actually consist of several distinct primary-color components, such as RGB triplets.

The system as described in PCT figure 40 has the advantage of providing our movement-permissive system yet requires less blocking of light than was called for by the methods presented in PCT figure 32 and 33a. Nevertheless that system has the disadvantage that each of the images, as seen by each of the eyes, is discontinuous: adjacent to each image pixel there is

a dark area of at least equal size, which provides no light from that eye's image. The image consequently appears to be of relatively low resolution and low quality.

Figure 11 provides an arrangement which avoids this disadvantage, and which will consequently be superior in some applications. It is characterized by the fact that light from the two images is distributed over the display in such a way that any given small area of the display surface will be presenting light from the left image in some color ranges, and also presenting light from the right image in some other color ranges. In this manner light from both images is spread across the display in a more evenly distributed manner, thereby minimizing the size of, or eliminating entirely, the areas of the display which do not present some light from any given image.

The system to be described may be contrasted to the classical parallax barrier system in which the blocking elements of the barrier layer line up in relation to the pixel elements of the display in such a way that the right eye sees pixels from the right image and the left eye sees pixels from the left image, in a manner well known in the art. The arrangement described by figure 11 uses the parallax barrier technique in a novel way. In this embodiment the barrier consists not of transparent areas alternating with opaque areas, but rather of a layer 40 which combines two or more color barriers, each of which has areas blocking light of a particular spectral range alternating with areas transparent to that spectral range. When the light of various spectral ranges is distributed throughout the display as described above, and barriers to each spectral range are placed appropriately on layer 40, the result is that the visibility, to each of the eyes, of light from each color range, is controlled by a parallax barrier arrangement, yet light from the appropriate image from at least some part of the color spectrum is visible to each eye throughout the entire surface of the display.

Figure 11 can be used to illustrate a number of embodiments of this idea. In the following paragraphs the embodiments will be described in terms of the example of three-color displays, such as RGB displays, yet it should be understood that the specific example is for illustrative purposes only and that the invention is not limited to those particular colors, nor indeed to systems of three colors. Equivalent implementations might be made with two, four, five, or more color ranges. Moreover, in the examples given in the following elements which filter colors (whether by absorbing certain color ranges or by reflecting certain color ranges) are discussed

as if they were physically fixed elements of variable optical characteristics with respect to color filtration could be used as well, on condition that at any given time their behavior approximates that described in the following for with respect to fixed color filtration systems.

In a first embodiment, we will consider the case where display 10 is capable of displaying all colors from either image at all points. If then display 10 were to display light of a first color range (e.g. red) from part of a right image in areas 102-104 and 108-110, and light of that color range from part of a left image in areas 105-107 and 111-113, and if areas of 42-44, 48-50, and 54-56 of layer 40 are transparent to light of that first color range, while areas 45-47 and 51-53 of layer 40 block light of that color from traversing them, then insofar as light of that first color range is concerned the arrangement constitutes the classic parallax barrier system for autostereoscopy. (Indeed, if all colors, rather than only the particular first range of color, were displayed, transmitted, and blocked in the aforementioned areas, then this would in fact be identical to the classical parallax barrier system.)

Other color ranges are also displayed on display 10 and transmitted or blocked by portions of layer 40, but according to this embodiment the blocking areas on layer 40 which block the several color ranges do not everywhere coincide. Similarly, on the display, for the left image and for the right image, at least some areas of the display displaying at least a second color range will not display a first color range, and at least some areas of the display displaying the second color range will not display the first color range. In a simple example according to this principle, red light from display 10 might be blocked by certain areas of layer 40, and green light from display 10 might be blocked by certain areas of layer 40, and the positions of the red-blocking areas and of the green-blocking areas would be different, in at least some areas of layer 40. Moreover there will be areas of the display which display red light from, say, the left image, and do not display, say, green light from that image, though they may display green light from the right image.

In the preferred implementation, the arrangement would incorporate the greatest possible differences in the placement of the various color ranges on display 10. Thus for example in a three-color display, if light from the first color range is displayed as stated above, then light from a second color range (e.g. green) from the right image might be displayed in areas 104-106 and 110-112 and light from that color range from the left image might be displayed in areas 101-103, 107-109 and 113-115, while light from a third color range (e.g. blue) from the right image would

be displayed in 106-108 and 112-114 and light of that color range from the left image would be displayed in 103-105 and 109-111.

Of course, on any part of layer 40 in which more than one color range is required to be blocked, then at that point either individual filters may be placed one behind another to achieve this effect, or else a single filter which is opaque to both color ranges could be used.

On barrier layer 40, for each of the color ranges, areas which are transparent to that color range alternate with areas which block that color range, the pattern being repeated along the width of layer 40. The placement of the specific areas with respect to each particular color range is such as to constitute the classical parallax barrier system with respect to that particular color range, as was illustrated above for the first color range. Thus, given the placement of colors from the two images as stated in the previous paragraph, areas 44-46, 50-52 and 56-58 would be transparent to light of the second color range and areas 41-43, 47-49, and 53-55 would be opaque to that color range, and areas 46-48 and 52-54 would be transparent to light of the third color range, and areas 43-45, 49-51, and 55-57 would be opaque to that range. (The placement of blocking areas on layer 40 specified in this and in the preceding paragraph will be referred to in the following as "filter arrangement A".)

Thus, with respect to each color range, layer 40 presents a parallax barrier, yet the barrier elements of the various color ranges are placed differently on layer 40. Consequently, while each eye sees the all the light from the image appropriate to it and does not see any light from the image inappropriate to it, yet there are no "holes" in the picture, no area of the display which fails to display at least some light from both left and right images. (Such a display will be called a "dense" display in the following.)

Of course, the technique just described may be combined with our movement-permissive system. That purpose might be accomplished in the manner described in PCT fig. 32-33a, by using opaque areas on layer 40, or areas which do not display light from either image on display 10. However a preferred implementation can be accomplished simply by reducing the width of each area of display 10 displaying each particular color range to an area smaller than the areas named above.

Figure 11 also illustrates this implementation. Consider the case in which the right image light of the first color range is displayed only in areas 103 and 109 (rather than in areas 102-104

and 108-110), while light of that color range from the left image is displayed only in areas 106 and 112 (rather than in areas 105-107 and 111-114). Similarly, right image light of the second color range is displayed at 105 and 111, left image light of the second color range is displayed at 102, 108, and 114, and light of the third color range of the right image is displayed at 107 and 113 and that of the left image and the third color range is displayed at 104 and 110. (This arrangement of display colors is called "display arrangement B" in the following.) Consider also that the color filter elements of layer 40 are as stated above with respect to the first embodiment, that is, layer 40 is constituted as described in "filter arrangement A."

It can be seen that reducing in size the display areas of each color range for each image, while leaving unchanged the size and placement of each of the areas on layer 40 which blocks light from a particular color range, creates precisely the situation described in PAT (figure 32) describing our movement-permissive system. Inspection of the figure will demonstrate that for each numbered area of display 10, its displayed color can be seen by the appropriate eye and not seen by the inappropriate eye, because areas of layer 40 transparent to that color stand between that particular area of the display and the appropriate eye, and areas of layer 40 which block that color stand between that area of the display and the inappropriate eye. It can be seen as well that, for each numbered area of display 10, since three contiguous numbered areas of layer 40 permit the passage of light from that display area to the appropriate eye and three contiguous numbered areas of layer 40 prevent passage of light from that display area to the inappropriate eye, consequently considerable movement of eyes 20 and 30 could take place, left and right and forward and back, without that movement reducing the appropriate eye's ability to see all the light emanating from the particular display area, and without increasing the inappropriate eye's ability to see light from the particular display area.

Since the discussion of the preceding paragraph relates to any random numbered area of display 10, it is clear that it applies equally well to display 10 as a whole. In other words, since it is true of each eye with respect to each numbered area of display 10 that that eye can see light from the image which is appropriate and not see light from the inappropriate image, and that this continues to be the case when that eye moves moderately left and right and forward and back, then it is true of the arrangement as a whole that throughout the width of display 10 each eye of the viewer will see its appropriate image and only its appropriate image, and will continue to do

so while moving moderately to the left and right and forward and back.. Thus the figure describes an autostereoscopic system which incorporates a form of our movement-permissive system yet in which the display presents no large gaps (none as large, for example, as an entire RGB triplet) in the displaying of the right and left images.

Of course, the specific configuration presented above is merely an example of the way in which a color display and color filter system can provided an autostereoscopic view without large gaps in the display of light from both images, while allowing for some freedom of motion on the part of the viewer. The arrangement might relate to two or four or five or more color ranges rather than three, and the display area displaying light from each color range might be either wider or narrower than that specified in the example.

The particular selection of color ranges and image sources described above does however presents an interesting feature. If the first color range is taken to be red, the second green, and the third blue, then the situation described corresponds closely to popular types of RGB display frequently used in televisions and liquid crystal displays (e.g. notebook computers), as well is in color monitors, where the "shadow mask" system used for displaying color in many CRT displays inherently divides the display area into areas of discrete color, which could then be directly aligned with a filter layer 40 at an appropriate distance and with appropriately placed and sized subdivision.

In any case, for any display system with RGB characteristics, the embodiment can be implemented by providing a layer 40 at appropriate distance with appropriately placed and sized blocking areas, and by displaying display pixels which mix the light from different color ranges from the left and right image pixels in an appropriate manner. For example, the display might present (in order) red from the left image, green from the right image, blue from the left image, red from the right image, green from the left image, blue from the right image, then again red from the left image, and so on, the pattern repeating itself across the width of the display. Stating the same thing in terms of RGB triplets, a first triplet would combine red from the left, green from the right, and blue from the left image, and the following triplet would combine red from the right, green from the left, and blue from the right image. Similar combinations could of course be made for systems based on two colors, four colors, or more.

The embodiments described above can also be applied to any display whose light source is

comprised of any combination of colors however generated, if that display is first filtered to provide for regions of particular color ranges, as described in fig 41 of PCT.

The techniques described above can be used in the context of any technique used to create an impression of continuous color ranges by combining elements of particular color in controlled amounts. Many printing processes, for example, are of this nature. That is, the system is also applicable to context in which pigments are used to absorb color ranges from ambient light, and reflect back particular ranges of color. In particular, the arrangement described above can be applied to contexts such as the printing of books and magazines, billboard-type advertising displays, and so on. Printed pictures, having absorbed certain color ranges from the ambient light and reflected the unabsorbed color ranges, are seen by observers as having color in much the same manner as are displays which generate light, on condition of being well illuminated. Thus a printed image may display much the same color characteristics as a light-generating display source, and the method described above will work on it as well. In the case where the light illuminating the printed picture must pass through the color filters to reach the printed matter, a light source which is both diffuse and sufficiently powerful will be required, but if such a light source is available the arrangement described will provide an autostereoscopic image as well. Specifically, a printed autostereoscopic image may be achieved by printing an image in two layers, with a first layer corresponding to the display 10 in figure 11, with colors from the left and right images distributed across the printed page as described with respect to display 10, then a transparent overlay of appropriate thickness (corresponding to the appropriate distance of layer 40 to display 10, which depends in turn on the width of the areas into which display 10 is divided, as described in figure 24 of PAT) placed on the image, and on that transparent layer, filter elements blocking particular colors, (described above as layer 40) are printed with transparent inks, or provided through any other printing or photographic process.

In another embodiment, these principles can be applied also to the case of a stereoscopic projection system. We showed in PCT figure 38 that it is possible to project a pair of full-color images through a color filter subdivided into areas filtering particular colors, and view an autostereoscopic image as a result, on condition that the projectors and the viewers are positioned appropriately. Referring again to figure 11 here, consider a situation in which a full-color left image is projected from eye position 30 and a full-color right image is projected from eye

position 20, both projecting towards a projection screen 12 placed in the position of display 10. It can easily be seen that if areas 43, 49, and 55 of layer 40 transmit only light of the first color range, areas 45, 51, and 57 transmit only light of the second color range, and areas 41, 47, and 53 transmit only light of the third color range, and all the even-numbered areas of layer 40 transmit no light at all, then the image projected onto the projection screen in the place of display 10 will have precisely the characteristics described above as "display arrangement B". (In the following this arrangement of layer 40 will be called "filter arrangement B".)

As we have seen above, an arrangement consisting of a display in display arrangement B, when seen through a layer 40 arranged as described in "filter arrangement A", is exactly the construction of the embodiment described above. Thus, if we project a pair of full-color images from appropriate positions through a layer 410 which is layer 40 arranged as "filter arrangement B" onto a projection screen 12, and then view that projection screen, again from appropriate positions, through a layer 415 which is layer 40 arranged as "filter arrangement A", we will have a forward projection system with all the advantages of the embodiments described above, including a "dense" display as defined above, as well as the advantages of our movement-permissive system. (As shown in PCT figure 38, the geometry of these arrangements creates "sweet spots", and projectors of left and right images may be placed at any left and right eye positions.)

To complete the description of an embodiment of this invention as applied to a front projection system, we need only point out that the light allowed to pass through filter arrangement B is everywhere a subset of the light allowed to pass through filter arrangement A. That is, there is no light allowed to pass by filter arrangement B which would be blocked by filter arrangement A. Consequently it is possible to implement a projection system in which a layer 410 (layer 40 in filter arrangement A) substantially covers the projection screen (in a movie theatre, for example), and to provide a layer 415 (another layer 40 in filter arrangement B) which filters light from the pair of projectors which are placed in positions comparable to eye positions 30 and 20, but which are substantially above or below the positions of the viewers. Layer 415 could then be placed out of the line of sight of the viewers, and the light from the projectors after being filtered by layer 415 would then pass without hindrance or substantial alteration through layer 410, reach screen 12, and be reflected back to the viewer, passing again through layer 410

but not through layer 415.

Implementing this embodiment in the case of a back projection system is simpler. In that case, screen 12 is a translucent back projection screen, the projectors are behind the screen, a layer 410 is behind screen 12, and a layer 415 is between the screen and the viewers.

<u>System which helps viewers find the "sweet spot"</u>

An additional embodiment of this invention is an improvement on a system first described by M.P.Rehorn in U.S. 2820395. His system addresses the difficulty experienced by viewers of autostereoscopic systems which require the viewer to view the systems from particular positions ("sweet spots"). In practice, viewers viewing such systems often find it difficult to know whether they are in fact in the correct position. Rehorn describes a system which provides the viewer with independent feedback (that is, feedback not dependant on the success or failure of the autostereoscopic viewing itself) on the correctness of his position.

Rehorn's method has, however, a disadvantage. Feedback from his system is provided by color. When the viewer is in the proper position he sees a pure color (in his example, pure white or pure red) and when he is in an improper position he sees a mixed color (in his example, pink). Unfortunately, it can be as difficult to distinguish between, say, white and slightly pink, or red and red with a slight admixture of white, as it is to distinguish between correct autostereoscopy and autostereoscopy with a slight degree of crosstalk between the images. Consequently it would be advantageous to have a method in which the difference between correct positions and somewhat incorrect positions is more clear.

Assume that the position pairs 320 and 330 of figure 12 are sweet spot positions of an autostereoscopic system, for the left and right eye respectively, as are 340 and 350. The pair 330 and 340 is not a sweet spot: if the left eye is at 340 and the right eye at 330, the viewer will see reverse stereoscopy, that is, his left eye will see the right image and his right eye the left image. Aside from that particular spot, if his left eye is positioned e.g. somewhere between 330 and 350, and his right eye positioned somewhere between 320 and 340, then each eye will see some light from of its appropriate image and some light from its inappropriate image..

Layer 11 in figure 12 is a layer in a plane parallel to the plane of the display; in the preferred implementation, it would be in the plane of the display, perhaps surrounding the display surface. <u>As shown in figure 12, layer 11 is divided into areas, each of which displays an image, e.g. a</u>

geometric form. There are two such forms, alternating along the width of layer 11. When two of these forms are seen together they combine visually to produce an easily recognizable composite form. In the example presented in figure 12, if form 13 is seen to the left and form 14 is seen to the right, then the composite form constitutes the shape of an "X". If form 14 is seen to the left and form 13 is seen to the right, then the composite form is in the shape of a diamond.

Layer 40 is a layer placed between layer 11 and the viewer. It is opaque through most of its width, but provides a number of viewing apertures such as aperture 18, through which the viewer can see the forms presented by layer 11. The width of aperture 18 is such that if the viewer is in the sweet spot, he is able to see, through that aperture, a portion of layer 11 equal in width to that of two of the forms of layer 11, which is to say, the width of one composite form.

The composite form visible from the sweet spot is chosen to be so as to suggest that the position is appropriate. In our example, the viewer viewing the forms on layer 11 through aperture 18 will see a series of diamond shapes. Circular or elliptical shapes might be provided instead, as might any other shape which is easy to see and, preferably, would suggest completion or appropriateness to a viewer. The viewer viewing the forms on layer 11 from, say, positions 330 and 340, on the other hand, will see an "X" shape, easily distinguished from a diamond or circular shape. Similarly, from any intermediate position between the positions mentioned, the viewer would also see an "X" shape, and a lopsided one.

Consequently using this system the viewer can see at a glance whether he is in a "sweet spot", or is not. Note that though layer 10 may be in the plane of e.g. the display, and layer 40 may be in the plane of e.g. a parallax barrier, this is not a requirement: any arrangement which provides a clearly recognizable figure when the viewer's position is correct, and is clearly invisible or distorted when the viewer's position is not correct, would suffice as well. Moreover there is no necessary relationship between the size of e.g. aperture 18 and the size of the areas on e.g. a parallax barrier creating the autostereoscopic system, except insofar as is required to make the points at which the viewer sees symbols indicating that he is in a sweet spot do in fact correspond to the positions of the sweet spot of the autostereoscopic system. Consequently the size of the aperture, and the size of the figures on layer 10, may be considerably larger than the intervals used in a parallax barrier or two-layer polarizer system, and hence be easily seen by the viewer.

<u>Reducing flicker by combining stereo modulator systems with spatial multiplexing, using</u>

polarizing eyeglasses

In PCT in the discussion of figure 5 there we presented a system for overcoming certain disadvantages presented by various systems for stereoscopic viewing using eyewear incorporating polarizing filters and/or shutter means. To relate to specific systems currently being sold as examples of the problem to be solved, we here mention the "stereo modulator" systems currently sold by Nuvision Inc. and Stereographics Inc. which provides images which flicker somewhat , and the "uPol" system sold by Vrex Inc., which provides images of low resolution.

In figure 5 of PAT and PCT we presented a method of combining techniques similar to those used in the stereo modular systems with techniques similar to those used in the uPol system, to produce a display system which would have full resolution and a substantially reduced impression of flickering. The reader is referred to the discussion of PAT pages 36-38 for that discussion.

Figure 13, here, presents an alternative method for constructing an apparatus which is similar in form and identical in purpose to that of figure 5 in PCT.

At a time T1 a first image (either left or right image) is presented in subregions 31 of display 1, and a second image (either right or left image, correspondingly) is presented by subregions 32 of display 1. Polarizing filter 20 polarizes all light from the display uniformly. 30 is a "switcher" layer of switchable light rotating means. 39 is a layer consisting of areas 41 active in light rotation, and areas 42 inactive in light rotation. Areas 41 of layer 39 are placed so as to be near to subregions 31 of display 1and to correspond to them in size and position, and areas 42 of layer 39 are similarly sized and placed with respect to subregions 32.

23 is a set of eyeglasses where one eyepiece 24 consists of a polarizing filter in some orientation, and eyepiece 25 consists of a polarizing orientation orthogonal to that of eyepiece 24. The orientations of the eyepieces are chosen in such a way that when switcher layer 30 is inactive in light rotation, light from subregions 31 passing polarized by layer 20, unaffected by switcher layer 30 and turned by areas 41 of layer 39 is visible only to a first eye and blocked from the second eye, while light from subareas 32, polarized by layer 20, unaffected by switcher 30 and not turned by areas 42 is visible only to the second eye and is blocked from the first eye.

At time T1, then, light from the first image will be visible only to a first eye, and light from

the second image will be visible only to the second eye.

At time T2 switcher layer 39 is activated in light rotation, and the second image is presented in subregions 31 and the first image is presented in subregions 32. Since the polarization of the images is reversed by switcher 30, the first eye now sees light from subregions 32 instead of that from subregions 31, and the second eye sees light from subregions 31 instead of that from subregions 32.

Consequently, at both time T1 and time T2, the first eye sees light only from the first image, and the second eye sees light only from the second image. Yet at time T1 the first image is presented in subregions 31 and at time T2 it is presented in subregions 32, whereas at time T1 the second image is presented in regions 32 and at time T2 it is presented in regions 31.

As a result, each eye sees only its intended image at all times, yet the amount of light reaching a particular eye at time T1 is substantially similar to the amount reaching it at time T2. This result substantially reduces the impression of flickering, as contrasted to a system such as the "stereo modulator" systems in which at any given time one eye sees the entire screen and the other eye sees nothing. Moreover this system has an advantage over systems such as the uPol system, in that whereas at any given moment each eye sees only half the display surface (as is the case with the uPol system), yet over time each eye sees its appropriate image over substantially all the surface of the screen, which fact (due to persistence of vision) creates an impression of a more high-resolution, continuous image.

In an alternative construction, layers 30 and 39 may be combined: if layer 39 is e.g. an LCD element which has individually addressable areas which whose activity/inactivity in light rotation can be individually switched, then the function of layers 30 and 39 are combined in a single layer.

In yet another alternative construction, a switcher layer 49 may be used in the place of switcher layer 30, to similar effect.

Stereoscopic apparatus using a liquid crystal array

Yet another method for displaying stereoscopic images is described in figures 14 and 15.

In the following text, subregions of the display are generally referred to as "pixels," but by use of the word "pixels" no limitation is implied regarding the size or nature of the subregions. In

particular, a subregion of the display may be further subdivided into individual color elements (as is the case, for example, in an RGB display). Individual color elements (e.g., red) of what are customarily referred to as "pixels" are also included in the definition of "pixel" as used in the descriptions of this embodiment.

Element 100 in figure 14 is a display source capable of producing an image. A CRT picture tube, a liquid crystal display, or any other source may supply the image of element 100.

In some implementations, an LCD display for example, element 100 is physically divided into subregions 140 (sometimes referred to hereinafter as "cells", or "pixels"). In some implementations (a CRT computer monitor for example), division into pixels may be a matter of areas of control as exercised by computing and control means 150, rather than a physical division of the display hardware itself. In yet other implementations (an analog device such as a standard broadcast television receiver for example), there may be no physical division into pixels. Nevertheless it will be convenient in the following exposition to refer to "pixels" 140, which may be thought of either as physical subdivisions of the display device, or else as relatively small subregions of the display device corresponding to small subareas of the displayed images, each such subarea being of known dimensions and position.

Element 200 is an element capable of rotating light, or as defined above, a birefringent layer with individually switchable elements. Each local area 240 of element 200 is capable of rotating light in varying degrees under electronic control, or of switching on and off their rotating effect under electronic control, or both. Local areas 240 are also sometimes called "cells" in the following. The signals controlling cells 240 of element 200 are provided by control and computational means 250.

Although figure 14 shows element 200 as being somewhat distanced from element 100, this is for clarity of the drawing only; in practice, element 200 will be close to, or contiguous to, element 100. Moreover each individual pixel 140 of element 100 is used in conjunction with a cell 240 of element 200; consequently they are to be of similar size and placement. In particular, the placement should be such that substantially most or all of the light emanating from a pixel 140 will pass through the corresponding cell 240 on its way towards the eyes of the viewer. In the preferred implementation, dimensions of the light emitting (or light transmitting) cells 140 may be made slightly smaller than the dimensions of the corresponding light-rotating cells 240,

so as to ensure that substantially all the light from each cell 140 will enter the corresponding cells 240, even when the apparatus is viewed at an angle.

The following notation is used: if (a,b) designates the position of a cell in a two-dimensional array of cells, then $140_{a,b}$ designates the pixel from element 100 at (a,b), and $240_{a,b}$ designates the cell from element 200 which receives and transmits the light from $140_{a,b}$.

A left image and a right image are to be displayed by the apparatus, and it is assumed that the images can be expressed as an array of pixels whose dimensions correspond to the dimensions of the array of pixels 140 constituting element 100. (An actual division of the images into such pixels is not a requirement of the invention; the pixels are being referred to here merely as a means of expressing the relationships of intensities of light from various sources in small local regions, and their disposition.)

The intensity of light of the left image at (a,b) is referred to as $L_{a,b}$, and the intensity of light of the right image at that point as $R_{a,b}$. (The reader is reminded that the pixel $140_{a,b}$ may refer to a single color element within an RGB triplet.) The sum of those intensities is $S_{a,b} = L_{a,b} + R_{a,b}$

In operation, the left and right images are combined into what we will call the CI (Combined Intensities) image, and that image is displayed by element 100.

The CI image combines the intensities of the left image and of the right image. That is, the intensity of the light emanating from any particular pixel $140_{a,b}$ is a function of the intensity $L_{a,b}$ of the light from the corresponding pixel of the left image and the intensity $R_{a,b}$ of the light from the corresponding pixel of the right image. Depending on the method used in element 200, the mathematical function ("f_1") that expresses the combined intensity may be the sum of the component intensities, the square root of the squares of the component intensities, or some other function.

Between element 100 and element 200 is an optional polarizing layer 190. If the light emanating from element 100 is already polarized (as would be the case for example if element 100 were an LCD display), then layer 190 is unnecessary. If the light emanating from element 100 is not polarized (as would be the case for example if element 100 were a CRT display), then layer 190 polarizes that light uniformly. In either case the light that reaches element 200 is uniformly polarized.

Element 200 has the task of re-dividing the light from pixels 140 back into the original left and right images where the new left image is substantially similar to the original left image, and the new right image is substantially similar to the original right image . It does this by partially rotating the light which passes through it, or by rotating the light during some portion of a time period T and not rotating the light during another portion of time period T (where time period T will typically be short enough to avoid producing an impression of flickering), or by a combination of these methods.

Element 200 might, for example, be a standard LCD of the sort often used to produce notebook computer displays. Such an LCD is typically used in notebook computer displays together with a pair of polarizing filters, one before it and one after it, and the resulting configuration can display varying levels of light intensity ("grayscale") by rotating light to a selected degree or for selected durations.

Element 200 in figure 14 might be the same sort of LCD as is used in notebook computer displays and operate in similar manner with respect to its input signals, yet it is here used unaccompanied by the polarizing filters which usually accompany such an LCD in a notebook computer display. If, then, element 200 is provided with signals constituting an image, it can respond just as it does in the context of the notebook computer display, rotating light to various degrees, between 0% and 100% in each cell 240, just as it would in responding to "grayscale" input in a notebook computer.

If the "grayscale" signal provided to cell $240_{a,b}$ is appropriately chosen, then the amount of light rotated into a selected orientation A can be proportional to $L_{a,b}$, and the amount of light unrotated, or rotated into a selected orientation B 90 degrees from A, can be proportional to $R_{a,b}$. Since what we have described with respect to a particular pixel will be true of all pixels, the overall effect is to constitute a new left image in some polarization orientation OL and a new right image in a polarization orientation OR orthogonal to OL.

As an aid to understanding, this principle may be restated as follows:

As mentioned above, each subregion 140 of element 100 displays a pixel whose intensity is a function (f_1) of the intensities of pixels in corresponding positions from the first image and from the second image. Each cell $240_{a,b}$ of element 200 receives a signal $G_{a,b}$ which also depends on $L_{a,b}$ and $R_{a,b}$, and that signal determines the amount and the manner in which light is to be rotated

by cell $240_{a,b}$.

Signal $G_{a,b}$ is such that it causes the light from each pixel $140_{a,b}$ to be rotated in such a degree and at such times that, when averaged over a relatively short time period T, the intensity of the component of the light passed by $240_{a,b}$ which is in an orientation A is substantially proportional to $L_{a,b} / S_{a,b}$, and the intensity of the component of the light passed by $240_{a,b}$ which is in an orientation B is substantially proportional to $R_{a,b} / S_{a,b}$, where A is oriented substantially 90 degrees from B.

The signals $G_{a,b}$, over all elements 240 of element 200, constitutes a kind of image, which we will refer to as the "Discriminating Intensities" image, or "DI".

In a first version of this embodiment, element 200, under control of the DI image, separates the combined image CI into reconstituted components which are similar to the original left image and right image, where the new left image is emitted in a polarization orientation A and the new right image in a polarization orientation B, 90 degrees from A. If the viewer then wears polarizing eyeglasses which allow substantially only light of A orientation to reach his left eye and substantially only light of B orientation to reach his right eye, then each eye sees its appropriate image and stereoscopic viewing results.

In another version of this embodiment, the DI image can be modified so as to express the reconstituted image in the format of Rehorn's "image B", which can then be used to produce an autostereoscopic system, as will be described below.

The figure 15 illustrates the methods of this embodiment in greater detail, by way of a specific example. In figure 15 we have chosen to show element 100 as a liquid crystal computer display consisting of a light source 110, a uniform polarizing filter 120, a liquid crystal 130 which constitutes a birefringent layer with individually switchable elements 140, and an additional uniform polarizing filter 170.

We further assume in this example that the cells 240 of element 200 divide the light passing through them by the simple expedient of rotating that light 90 degrees during some portion of a time period T, and not rotating it during the remainder of the time period T. Note however that these assumptions are chosen for purposes of illustration only, and the scope of the invention is not limited to these choices.

Under these assumptions, operation of the apparatus would be as follows: for each physical

pixel 140 at position (a,b), computing means 150 would calculate the CI image pixel as the sum ($L_{a,b} + R_{a,b}$), that is, by adding the intensity of the corresponding left image pixel at point (a,b) of the image to the intensity of the right image pixel at point (a,b) of the image. (If appropriate, the resulting values might be multiplied by some constant factor to avoid expressions of intensity greater than 100% of what the display hardware is equipped to display.)

Computing means 250 (which of course could also be the same physical computer as computing means 150) would calculate the corresponding pixel of the DI image, which might be ($L_{a,b}$ / $S_{a,b}$), that is the ratio of the intensity of the left image pixel at point (a,b) to intensity of the CI image pixel at point (a,b), since under the assumptions the CI image pixel intensity is simply the sum of the left and right image pixels' intensities at that point.

For each pixel cell 140, element 100 would emit light corresponding in intensity to the CI image at that point. This light would enter the corresponding cell 240 of element 200. Although for clarity of exposition figure 15 has shown elements 100 and 200 as being somewhat separated, actual construction would place them contiguous or nearly contiguous to each other, so that substantially all of the light emanating from pixel $140_{a,b}$ of element 100 would enter cell $240_{a,b}$ of element 200.

Under our assumptions, the light from each cell 140 will enter the corresponding cell 240 which, under control of computing and control element 250, will rotate it during some portion of time period T, which portion depends on the relative intensities of the pixels from the left and right images at that point. For example if, say, 100% of the light of CI at position (a,b) comes from the left image, then the cell $240_{a,b}$ might rotate the light 100% of period T, whereas if only 20% of the light of CI was due to the left image, then the cell $240_{a,b}$ might rotate light only 20% of time period T. Of course, the directions could be reversed, so that a CI pixel 20% of whose intensity was due to the corresponding pixel from the left image might be rotated 80% of the time, and left unrotated 20% of the time.

The result for each pixel cell $240_{a,b}$ will be that an amount of light proportional to $L_{a,b}$, the pixel intensity of the left image, would be rotated into polarization orientation A, and an amount of light proportional to $R_{a,b}$, the pixel intensity of the right image, would be unrotated, and remain in polarization orientation B. Since for each pixel the intensity of the light being divided was the sum of the intensities $L_{a,b}$ and $R_{a,b}$, it is clear that the effect, over all the pixels of element 200,

will be that the left image now being created will be substantially similar to the original left image, and will be rotated into orientation A, and the right image now being created will be substantially similar to the original right image, and be transmitted in orientation B.

Note that our choice of which image is to be rotated was entirely arbitrary. If the rotated image is everywhere chosen to be the left image and the unrotated image is everywhere chose to be a right image, and if a viewer uses polarizing eyeglasses with a filter in A orientation on his left eye and a filter in B orientation on his right eye, then stereoscopic vision of the images will result. Similarly, the right image might be rotated and the left image unrotated, and the eyeglass filters adjusted accordingly.

The details above are provided by way of example and are not intended to limit the scope of the invention. It will be clear to one versed in the art that the arrangement described above can easily be modified to emit circularly polarized light, which the viewer would view using eyeglasses which analyze circularly polarized light, to similar effect. It will also be clear that for "rotated" and "unrotated" we might substitute "rotated to degree N" and "rotated to degree N + 90", and further that, as stated above, partial rotation (by application to the Kerr cell $240_{a,b}$ of a voltage which may be less than that required to create a 90-degree difference with the relaxed state) might be added to or substituted for time-sharing of the Kerr cell $240_{a,b}$ between the two images as here described. It is further clear that, in operation, the optimal means for sharing the light of a given pixel between two images might involve manipulating both the timing of the switching of the Kerr cell $240_{a,b}$ and also its voltage, and would further take into account such factors as the time delays involved in the switching operation itself, the behavior of the cell during the time of the switching, and so on. In general, the invention contemplates any method for dividing the light between the two images in such a manner that, when the transmitted light is viewed through polarizing filters, the pixel elements transmitted by the apparatus are comparable to the pixel elements of the original left and right images and the new left and the new right images are displayed in differing polarization orientations.

It is further clear that the computing means 150 and 250 referred to above need not be physically contiguous to the rest of the apparatus. It would be possible, for example, to have computing means 150 and 250 make the requisite calculations to transform a left and a right image into the CI and DI images at a remote site, and then broadcast or otherwise transmit the

CI and DI images to an apparatus which would display them, an element 100 displaying the CI image as transmitted, and an element 200 'displaying' the DI image as transmitted, with effects as described above.

The arrangement described above can further be used to produce an autostereoscopic display.

This can be done simply by modifying the choice of rotated and unrotated images across the face of element 200 in such a manner that Rehorn's "image B" results. We might, for example, alternate areas E and areas F across the face of element 200, where in areas E the left image is rotated and the right image unrotated, and in areas F the right image is rotated and the left image unrotated. Since the selection and placement of areas E and F is under electronic control of computing and control element 250, they may be placed on element 200, resized, and moved, in any manner which is convenient to the overall operation of the apparatus. In particular, their dimensions and positions can be modified in real time according to the distance and the position of the viewer or viewers, in order to conform to the requirements of the head tracking systems described elsewhere in this document and in PCT.

In other words, the apparatus pictures in figures 14 and 15 can be taken as a whole to be the display apparatus referred to as "display layer 500" in figure 7, where areas "E" and "F" of figures 14 and 15 correspond to areas 510 and 520 of figure 7 respectively.

In the above paragraphs and in figures 14 and 15 we have described how an arrangement of polarizing elements and birefringent layers with individually switchable elements can be used to constitute both an autostereoscopic system (without requiring eyeglasses) and a stereoscopic display system which does use polarizing eyeglasses, and we have pointed out the advantages of the system both for stereoscopic and for autostereoscopic display.

It would clearly be further advantageous for a single system to be able to present both the stereoscopic and the autostereoscopic displays in alternative use. For example, the same apparatus might be used to provide autostereoscopic display to a single user, (or to several users, utilizing techniques described in PCT), yet for multiple users a single user might enjoy the autostereoscopic display, and when it was desired for multiple users to observe the display, the glasses- based stereoscopic mode might be used to advantage.

Two ways in which this can be accomplished are shown in figure 16, which includes elements

80, 85, 130, 140, and optional 150 and 160 from figure 7, and in which elements 100, optional 190, and 200 from figure 14 fill the role of display 500 of figure 7. That is, the arrangement described in the context of figures 14 and figure 15 produces an image with the characteristics described by Rehorn as "image B", and the discussion of figure 7 explains how that image can then be viewed in autostereoscopic viewing, with the various advantages of the various systems described above.

Figure 15 shows several alternative configurations which allow the system to be used for stereoscopic viewing with glasses, for autostereoscopic viewing without glasses, or both.

For viewing with glasses, we have described above the distribution of images on layer 200 such that viewers with glasses can see the new left image with the left eye and the new right image with the right eye. Layers 140 and optional 160, however, are polarizing layers, and would interfere with the process of viewing with glasses. Consequently a system designed exclusively for viewing with glasses would use layers 100, possibly 190, use 200, use glasses 1000, and not require layers 130, 140, 150, nor 160.

If it is desired to make a system which can function in both modes, one possible arrangement is to construct the apparatus in such a way that layer 140, and optional layers 150 and 160 if present, are removable. Note that if layers 150 and 160 are not in use, then the only layer which needs be removed for viewing with glasses is layer 140, which is a unified polarizer with no electronic connections to the system, consequently an arrangement which contemplates frequently installing it and removing it is not impractical. (Layer 130, which is not required for glasses viewing, will nevertheless not hinder glasses viewing if it is inactivated in light rotation. In other words, while layer 140 must be removed, layer 130 can simply be turned off.)

Nevertheless, it can be further advantageous to have a system which requires no gross physical change, such as physically removing layers, when converting from glasses viewing to autostereoscopic viewing. Such an arrangement is presented by the addition of layer 165, which

is an additional liquid crystal layer, a birefringent layer with individually switchable elements, similar to layer 200. In operation as a display for glasses viewing, layers 200, 130, and 150 are either inactive in light rotation, or activated in such a way as to transmit the image arriving at 200 through to layer 165 substantially unchanged, or changed in a uniform manner which does not destroy the CI image. Layer 165 is then used as described in the discussion of layer 200 above (that is, layer 165 is used as if it were layer 200), and the viewer can use glasses 1000 to view the stereoscopic image.

To use same arrangement for autostereoscopic viewing, all that needs to be done is to switch layer 165 to be inactivated in light rotation; this done, the apparatus functions as described above for autostereoscopic viewing, and layer 165 does not substantially influence the process.

On further advantage of the system may be noted in passing: if display 100 displays a single image (rather than a left and a right image), all the switching layers (200, 130, 150, 165) are inactivated, or activated only as required to allow light best to pass the polarizing layers (190, 140, 160), then the apparatus can be used to display normal non-stereoscopic images as well.

Thus we have described an apparatus which provides a glasses-based stereoscopic display with the advantages of full resolution, no flicker, and not requiring fast switching liquid crystals, and which also provides an autostereoscopic display with the advantages of full resolution, no flickering, head tracking both sideways and with respect to depth and which can compensate for some degree of head tilting and which can be constructed as a flat screen, and which further provides the advantage of converting between glasses-based viewing and autostereoscopic viewing by electronic switching and without moving parts, and which has the further advantage of being able to display normal non-stereoscopic images.

Thus, the present embodiment, when combined with the various methods described above and in PCT for utilizing Rehorn's "image B" in autostereoscopic systems, will have all the advantages described above for the use of such systems (e.g., full resolution without flicker), plus the additional advantage that the apparatus itself will be relatively flat and relatively simple, and thus constitute an attractive and convenient autostereoscopic display system.